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Highlights of our progress include significant improvements in intensity and track predictions for hurricanes with the use of physical initialization techniques and high resolution (T170) global model forecasts using the FSU global spectral model. These improvements are supported by results of forecasts made for Hurricanes Florence (1994) and Opal (1995) which are detailed in this report.

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Annual Technical Report

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Project Title: Tropical Numerical Weather Prediction and Collaboration with the Naval Research Laboratory

Progress for Period: 07/01/95 - 06/30/96

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Highlights of our progress include significant improvements in intensity and track predictions for hurricanes with the use of physical initialization techniques and high resolution (T170) global model forecasts using the FSU global spectral model. These improvements are supported by results of forecasts made for Hurricanes Florence (1994) and Opal (1995).

Hurricane Opal

The observed and predicted tracks for a four day forecast of hurricane OPAL are shown in fig(1a). Here one of these (to the left) is the observed track and the other was obtained from a forecast made at the resolution T170 with the FSU global spectral model that includes physical initialization. This forecast does have an error of roughly 100 km on day four of the forecast. Even this order of error for landfall can provide useful guidance.

The maximum wind for OPAL at 850 mb (observed and modeled) are shown in fig. (1b). The model rainfall distribution at the time of maximum intensity is shown in fig. (1c) and the isotach distribution of the models 850 mb wind at the time of maximum intensity is shown in fig. (1d). Overall the model simulations are quite encouraging.

We have pursued two avenues for the interpretations of intensity changes of hurricane OPAL. Potential vorticity and angular momentum transports into the storm occur both in the upper and the lower troposphere. First we constructed forward trajectories using the predicted three dimensional motion field $(u,v,\dot{\sigma})$ for parcels that originate in the rear i.e. west of the arriving upper trough and terminate in the storm area where the radius $r \leq 200$ km. The descending parcels, in the rear of the upper trough, arrive over the storm area with a large earth's angular momentum Ωr^2, as they arrive in the storm area the reduction in r results in a large increase in the relative angular momentum $V_\theta r$ and a substantial increase in V_θ the intensity of the

storm. Angular momentum is however not entirely conserved as these parcels arrive and enter the storms circulation. There exists a field with substantial generation and destruction of potential vorticity on the meso scale over the storm area. The gradient of angular momentum is closely related to the potential vorticity. There the diabatic effects on the potential vorticity play a crucial role in dictating the final values of the angular momentum that the parcels realize in their motion into the storm's circulation. Potential vorticity budgets that illustrate the advective, diabatic and frictional contributions and explain the model output of the intensity are shown in fig. (1b). A second avenue for the understanding of the storms intensity came from an examination of the inflow channels of hurricane OPAL in the lower troposphere. Here the issues of outer angular momentum of parcels that enter the storm's circulation and how they are shaped by pressure and frictional torques also determines the storm's intensity. If the inflow channels are covered by a large population of meso convective precipitating elements then the inflowing air can lose substantial angular momentum prior to reaching the inner area of the storm. However, if the channels open up (suppressed convection) for short periods of time, then the large angular momentum of the storm's environment can enter the inner area of the hurricane resulting in an intensification of the storm. We show that both the upper tropospheric PV advections (and their substantial modifications by the diabatic effects) and the lower tropospheric angular momentum advection along the inflow channels (and their substantial modification by the pressure and frictional torques) finally shapes the intensity of OPAL during its life history.

Another important feature during OPAL's life history was a warmer sea surface temperature anomaly over the northern Gulf of Mexico. That evidently contributes to the distribution of convection and the resulting intensity diagnosed by our studies.

Hurricane Florence

Two somewhat unique aspects of Hurricane Florence include the recurvature to the east and the intensity variations that occurred between 4 November and 8 November. The observed track is shown in Figure 2a.

Using the FSU global spectral model which includes detailed initialization and physical parameterization, a series of experiments, on the medium time frame, was carried out at a resolution T170 (transform grid separation $\approx$70 km). Sensitivity experiments deal with the effects of physical initialization of precipitation from high resolution microwave data derived from the SSM/I instruments on the DMSP satellites (F10, F11, and F12). Control experiments do not include physical initialization. Model forecasts were run starting on 4 November at 1200 UTC.

The results of our study show that a major improvement in the storm forecasts results from the rain rate initialization. Figures 2b and c illustrate the control and physically initialized forecasts. Both the track and intensity variations are improved using physical initialization. Figure 2d illustrates the maximum wind speed of the storm (intensity) for the observed winds, the control experiment and the physically initialized experiment. The observed maximum wind speed reached approximately 95 knots, whereas the physically initialized forecast had a maximum wind speed of around 85 knots. The track forecasts and intensity variations were both reasonably captured by the model that used physical initialization.

Intensity variations that occurred between 4 November 1200 UTC and 8 November 1200 UTC are of particular interest. Figure 2e shows Reynold's weekly OI sea surface temperatures. Also plotted are the observed and physically initialized tracks from hours 48 to 96. The storm was quite intense at hour 20 of the forecast, it weakened around hour 50 and strengthened again

around hour 80 of the forecast. There were well marked anomalies in the sea surface temperatures over these regions of intensity changes. The more intense phase of the storm clearly noted over regions of warmer SST anomalies and the weaker intensity of the storm was seen over the colder water.

We are presently continuing our studies of this storm to include 1) experiments with a smoothed SST field (SST without warm & cold anomalies noted above) and 2) diagnostic studies on intensity variations which will examine the upper tropospheric PV and eddy angular momentum fluxes.

T.N. Krishnamurti ONR Research related publications for 1995-96.

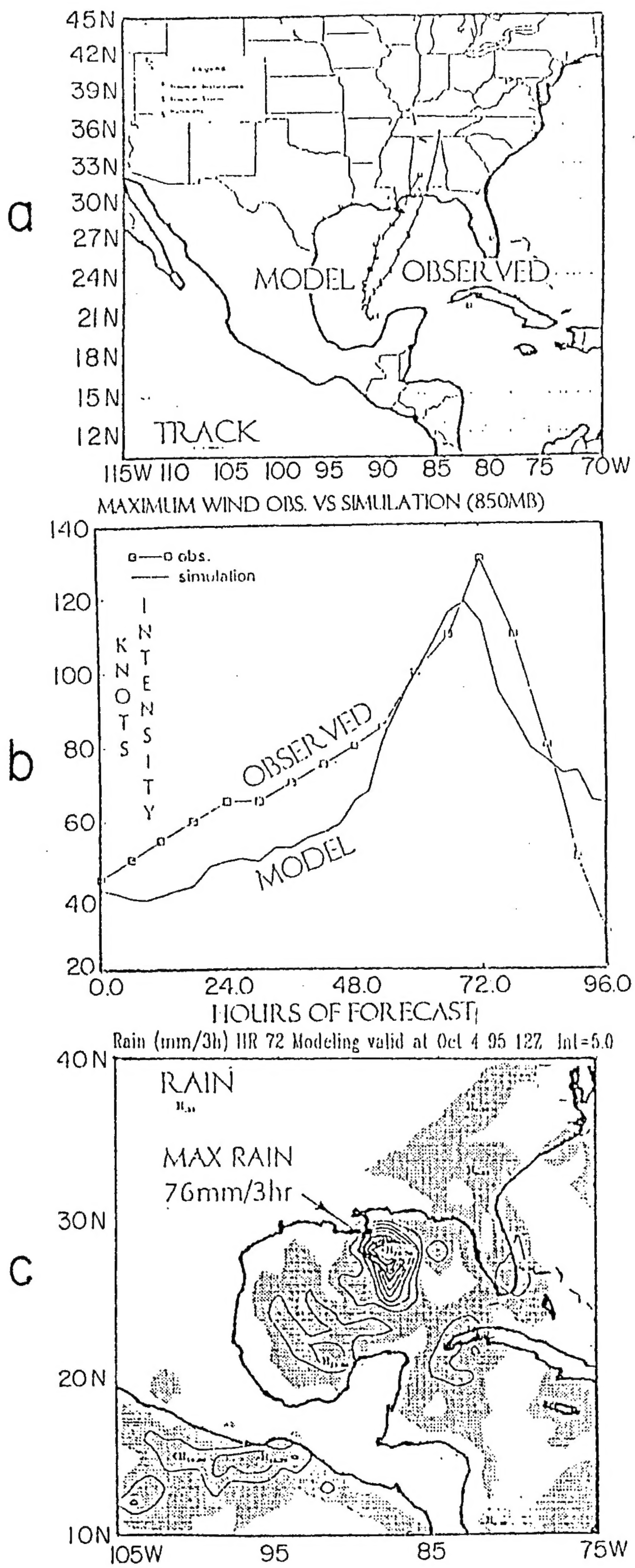
1996: (with H.S. Bedi, G.D. Rohaly, D.K. Oosterhof, R.C. Torres, E. Williford and N. Surgi). Physical Initialization. *J. Atmospheric Oceans* (In press).

1996: (with R. Correa-Torres, G. Rohaly and D. Oosterhof). Physical Initializaton and Hurricane Ensemble Forecasts. (Submitted for publicaton in *Journal of Weather and Forecasting).*

1996: (with P. Alpert, S.O. Krichak, U.Stein and M. Tsidulko). The relative roles of lateral boundaries, initial conditions and topography in mesoscale simulations of Lee, Cyclogenesis. (Accepted for publication in J. Applied Meteorology)

1996: (with H.S. Bedi). An overview of physical initialization. *J. Met. Atmos. Physics,* Oct. 95 issue.

1995: (with S.K. Roy Bhowmik, Darlene Oosterhof, Gregg Rohaly and Naomi Surgi). Mesoscale Signatures within the Tropics Generated by Physical Initialization. *Monthly Weather Review,* **123**, 2771-2790.



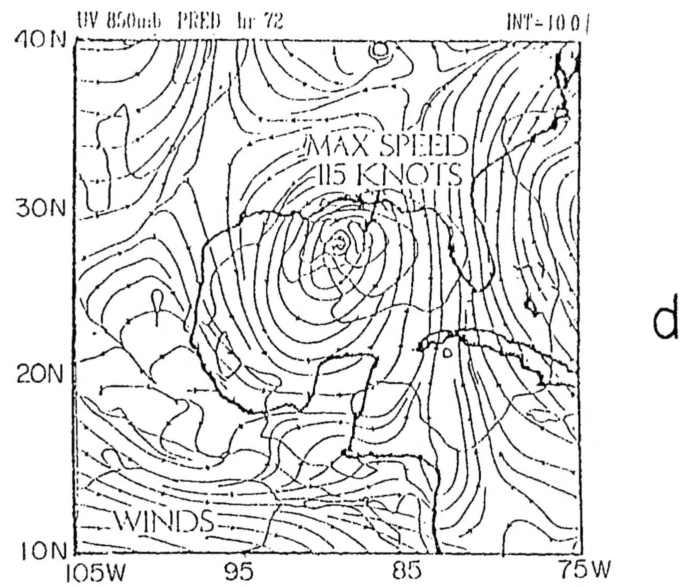


Fig. 1 Hurricane OPAL. October 1-5 1995, 12 UTC.

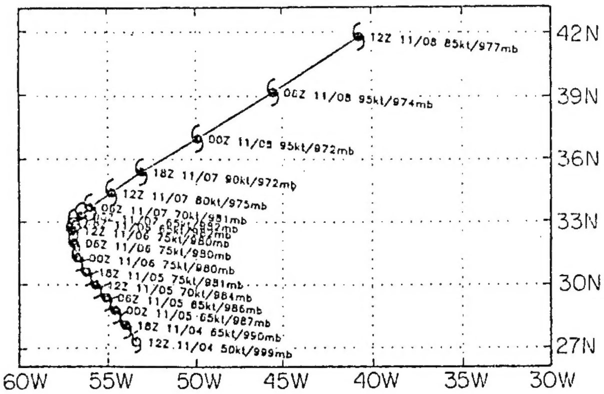
a) Observed and predicted tracks.

b) Intensity (max. wind ms^{-1}).

c) Rainfall between hours 72 and 75.

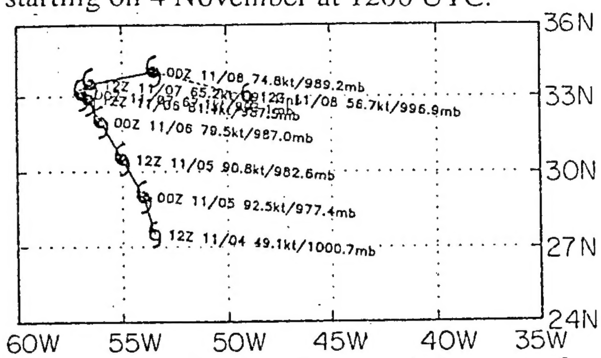
d) Isotach (ms^{-1}) at 850 mb at hour 72.

a



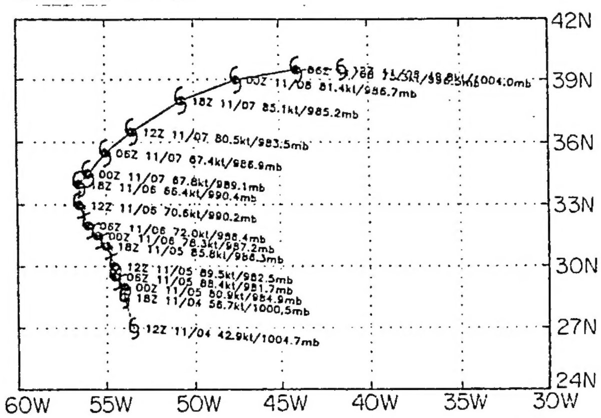
Track of hurricane Florence starting on 4 November at 1200 UTC.

b



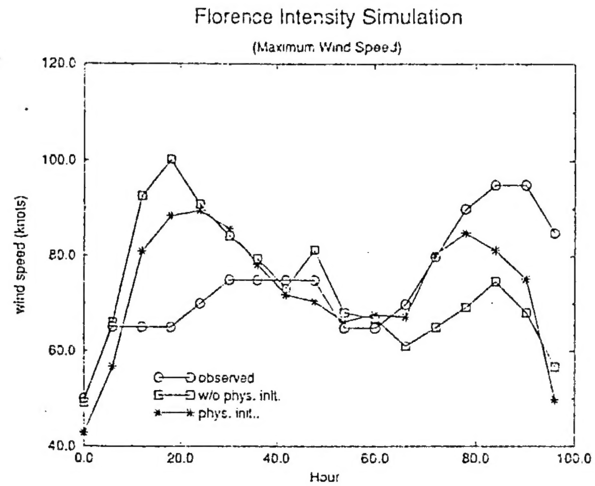
Track of control forecast for hurricane Florence starting on 4 November at 1200 UTC.

c



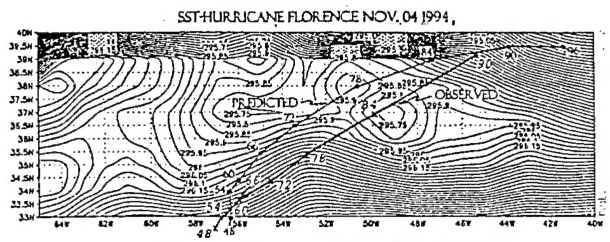
Track of physically initialized forecast for hurricane Florence starting on 4 November at 1200 UTC.

d



Intensity simulation of hurricane Florence illustrating maximum wind speeds for 96 hr. forecast for observed winds, control experiment and physically initialized experiment.

e



Reynolds weekly OI SST for the week of 4 November 94 with the observed and physically initialized tracks from hours 48 to 96.